

Automated Antenna Design with Evolutionary Algorithms

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I. abstract

Current methods of designing and optimizing antennas by hand are time and labor intensive, and limit complexity. Evolutionary design techniques can overcome these limitations by searching the design space and automatically finding effective solutions. In recent years, evolutionary algorithms have shown great promise in finding practical solutions in large, poorly understood design spaces. In particular, spacecraft antenna design has proven tractable to evolutionary design techniques. Researchers have been investigating evolutionary antenna design and optimization since the early 1990s (e.g.,¹⁻³), and the field has grown in recent years as computer speed has increased and electromagnetic simulators have improved.

Two requirements-compliant antennas, one for ST5⁴ and another for TDRS-C,⁶ have been automatically designed by evolutionary algorithms. The ST5 antenna is slated to fly this year, and a TDRS-C phased array element has been fabricated and tested. Such automated evolutionary design is enabled by medium-to-high quality simulators and fast modern computers to evaluate computer-generated designs. Evolutionary algorithms automate cut-and-try engineering, substituting automated search through millions of potential designs for intelligent search by engineers through a much smaller number of designs. For evolutionary design, the engineer chooses the evolutionary technique, parameters and the basic form of the antenna, e.g., single wire for ST5 and crossed-element Yagi for TDRS-C. Evolutionary algorithms then search for optimal configurations in the space defined by the engineer.

NASA's Space Technology 5 (ST5) mission⁵ will launch three small spacecraft to test innovative concepts and technologies. Advanced evolutionary algorithms were used to automatically design antennas for ST5. The combination of wide beamwidth for a circularly-polarized wave and wide impedance bandwidth made for a challenging antenna design problem. From past experience in designing wire antennas, we chose to constrain the evolutionary design to a monopole wire antenna. The results of the runs produced requirements-compliant antennas that were subsequently fabricated and tested (see photo below).

The evolved antenna has a number of advantages with regard to power consumption, fabrication time and complexity, and performance. Lower power requirements result from achieving high gain across a wider range of elevation angles, thus allowing a broader range of angles over which maximum data throughput can be achieved. Since the evolved antenna does not require a phasing circuit, less design and fabrication work is required. In terms of overall work, the evolved antenna required approximately three person-months to design and fabricate whereas the conventional antenna required about five. Furthermore, when the mission was modified and new orbital parameters selected, a redesign of the antenna to new requirements was required. The evolutionary system was rapidly modified and a new antenna evolved in a few weeks.

The evolved antenna was shown to be compliant to the ST5 mission requirements. It has an unusual organic-looking structure, one that expert antenna designers would not likely produce. This antenna has been tested, baselined and is scheduled to fly this year.

In addition to the ST5 antenna, our laboratory has evolved an S-band phased array antenna element design that meets the requirements for NASA's TDRS-C communications satellite⁶ scheduled for launch early next decade. A combination of fairly broad bandwidth, high efficiency and circular polarization at high gain made for another challenging design problem. We chose to constrain the evolutionary design to a

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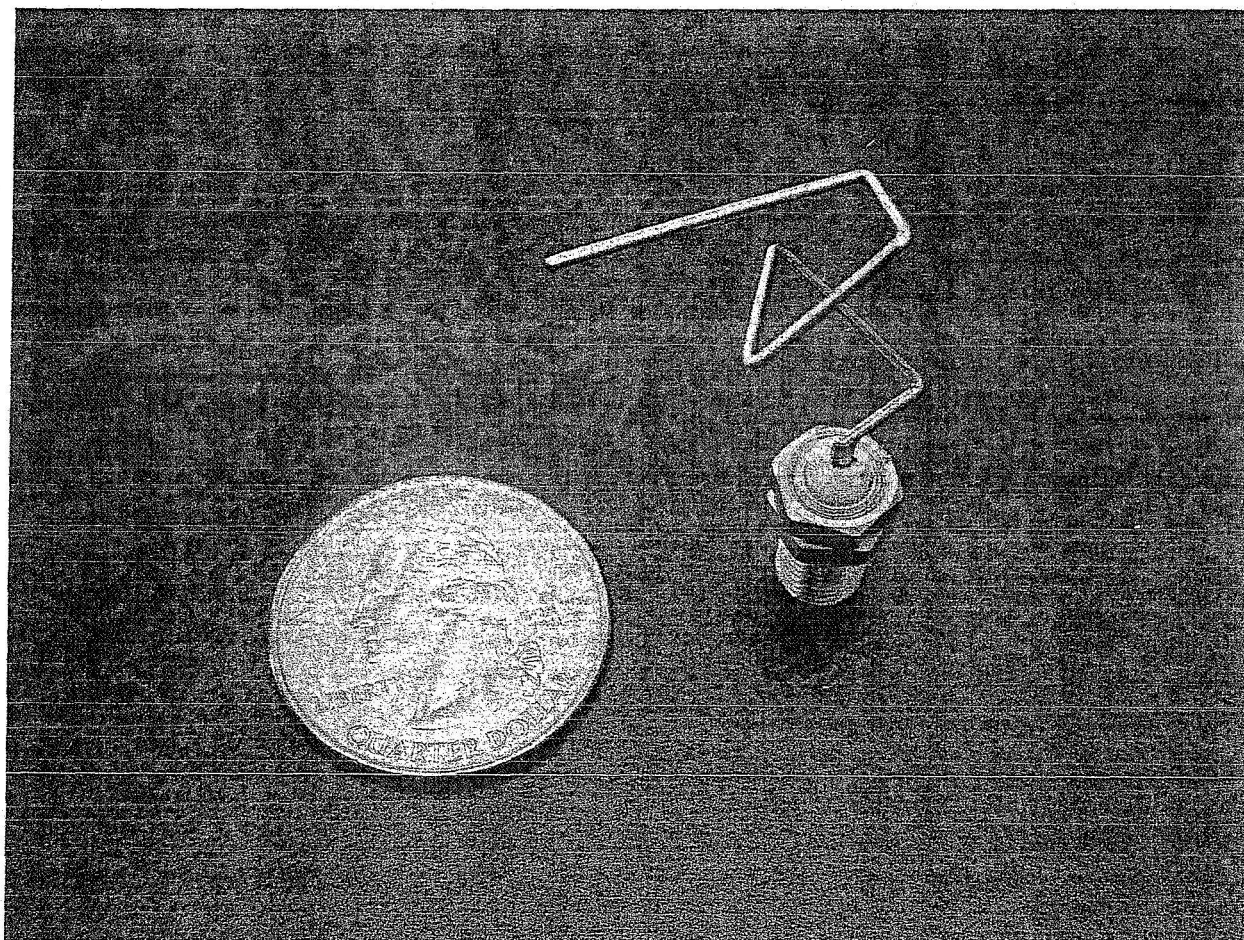


Figure 1. Photograph of the evolved ST5 antenna.

crossed-element Yagi antenna. The specification called for two types of elements, one for receive only and one for transmit/receive. We were able to evolve a single element design that meets both specifications thereby simplifying the antenna and reducing testing and integration costs. The highest performance antenna found using a genetic algorithm and stochastic hill-climbing has been fabricated and tested. Laboratory results correspond well with simulation.

Aerospace component design is an expensive and important step in space development. Evolutionary design can make a significant contribution wherever sufficiently fast, accurate and capable software simulators are available. We have demonstrated successful real-world design in the spacecraft antenna domain, and there is good reason to believe that these results could be replicated in other design spaces.

References

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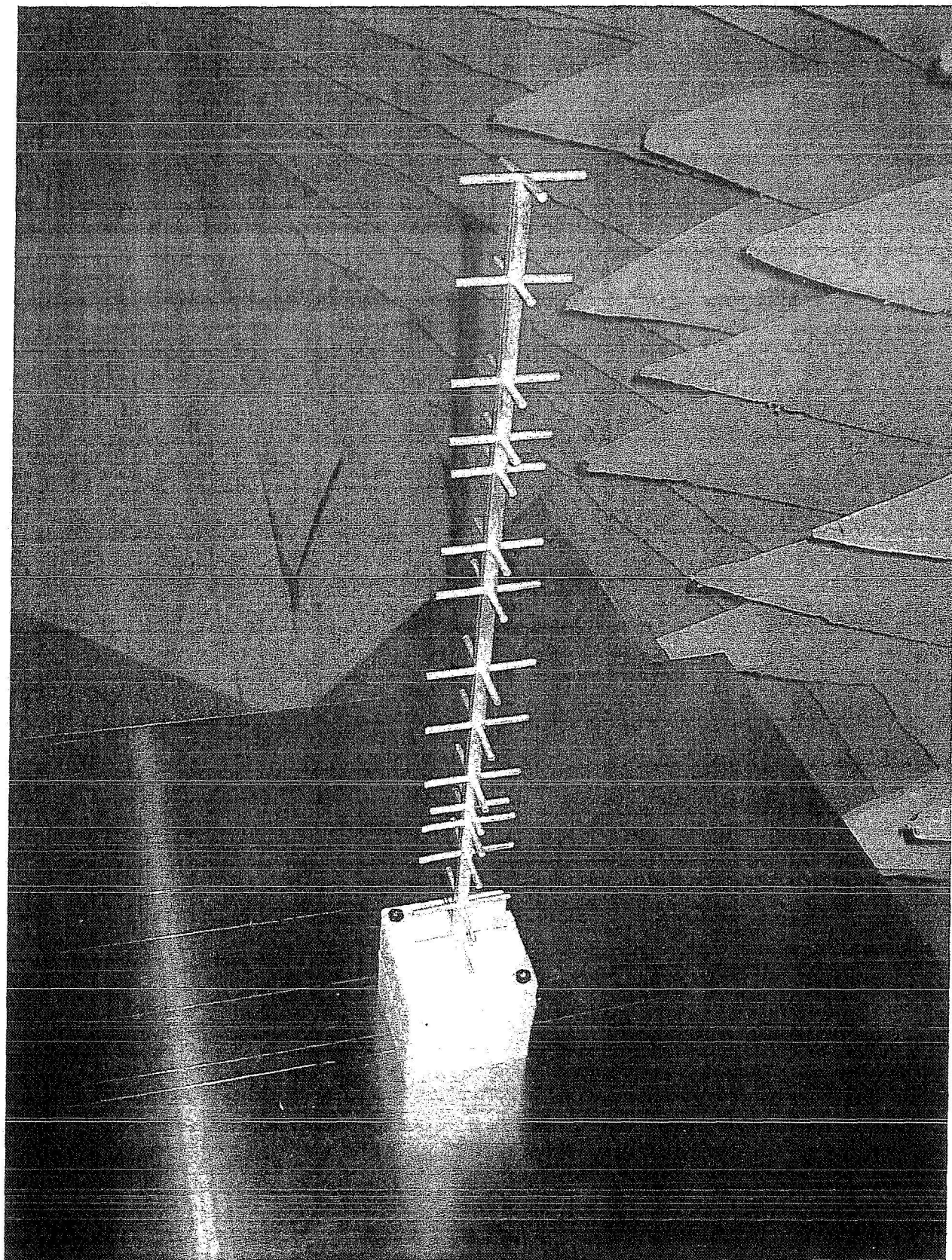


Figure 2. Best evolved TDRS-C antenna.